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# AGING AVIONICS- A SCIENCE & TECHNOLOGY CHALLENGE OR ACQUISITION CHALLENGE?

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The fleet of aircraft which we have today, represents 90% of the aircraft which we will have well into the next century. With defense budgets shrinking, fewer new aircraft will be purchased. Avionics modernization is the highest leveraged approach to maintain and increase capability. This treatise discusses the problems associated with our existing fleet of aircraft, both from a maintenance and modernization perspective. Examples of obsolescence and retrofit issues are provided to highlight the seriousness of the problem.

The science and technology challenges are the focus of a small set of technologies aimed at reducing the cost of our aging systems. These costs include maintenance as well as upgrade costs. Aging systems are different from new systems because there is an existing infrastructure. It is much easier to start from "scratch" than modify something already in existence. Specific technology areas that will be discussed include:

a. Avionics software
b. Group A Modification
c. Avionics Maintenance
d. Application of COTS products
e. Obsolescence/Environment for Rapid Design Changes

Acquisition related issues have to be addressed in consonance with the Science and Technology challenges. Issues that will be discussed include: Open systems, planned technology insertion/planned obsolescence, verification/validation, warranties/repair strategies and organic/contractor support. As part of this acquisition discussion, industry pursuit of a product line investment strategy will be addressed as their adoption of best commercial practices continues.

A possible Avionics S&T strategy will be discussed which outlines an approach for infusion and transition of advanced technologies into the existing fleet given an acquisition friendly environment. Discussion on modeling, simulation, and prototyping will be provided to further explain the fleet wide application of these technologies.

## Background

Today DoD is being challenged to do more with less. This has focused attention on affordability opportunities and challenges with emphasis on commercial or commercial-based avionics and electronics. The life of older (legacy) aircraft is being extended while their avionics systems are becoming obsolete, and more difficult and expensive to maintain and support. New aircraft also need to be more affordable and have functionality and performance equal to or exceeding that of existing systems. Lower upgrade and support costs for existing aircraft and lower acquisition and support costs for next generation avionics systems, are primary challenges.

Our Nation's aircraft are capable, but their electronics are old and aging rapidly. In the post 2000 era, these aircraft will experience worldwide deployment in support of our active front-line forces. The majority of our Nation's fleet of aircraft through 2020 will be legacy aircraft as shown in Figure 1.

The tactical fighter fleet is aging rapidly in large numbers, with the projected average age of all fighters in the USAF and Navy inventories estimated to be over 20 years by the year 2020.

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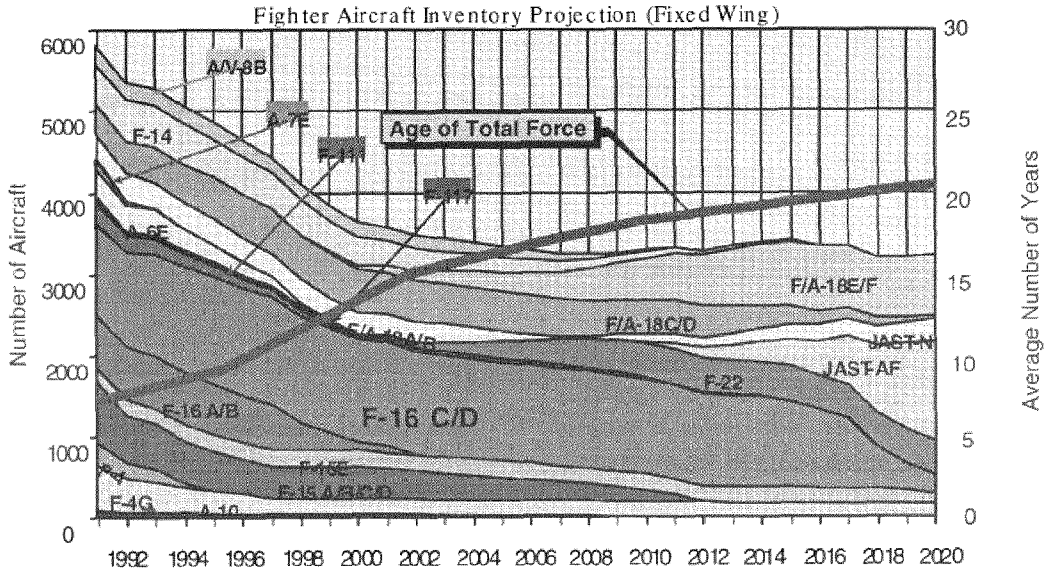


**Figure 1 Tactical Fighter Inventory**

Clearly, avionics on these aircraft will require modernization during the next decade if these weapon systems are to maintain their readiness status. Future aircraft modernization will focus increased capabilities which require effective communication with active forces, concurrent use of weapons, compatibility with electronic combat systems, up-to-the-minute access to off-board intelligence, an effective means of cooperative targeting, high accuracy bombing with inertial guided weapons, and on-board training for pilots and ground personnel. These capabilities must be inserted affordably and within the cost or schedule constraints imposed by the military budget.

Many technological advances having profound implications for military capabilities are the result of research and development conducted by commercial firms for essentially the commercial markets. Digital products found in personal computers have become the center of focus on commercial technology insertion as they have become much more powerful than many of the computers being used in our weapon systems, and at dramatically lower prices (see Figure 2). The power of the processors gives intelligent weapon systems their capabilities. The combined factors of expanded capabilities and lower costs are clearly compelling reasons to integrate these commercial technologies into our existing and advanced weapon systems.

## Legacy aircraft issues and reasons for upgrade

Recent DoD budgets and the political climate are forcing the United States military aircraft to remain operational well beyond their projected service life. These life cycle extensions have prompted many legacy aircraft upgrade programs. In addition, today's military aircraft must perform an increasingly broad range of missions from tactical/strike to reconnaissance and electronic warfare. These emerging missions encompass a wide range of avionics functions, performance, and cost. Several platforms are in need of upgrades due to the need for increased connectivity, the lack of spares, and directed initiatives that require increased avionics performance/functionality. However, current budgets have been reduced to the point where it is difficult to meet all requirements using the traditional upgrade methods employed during the 1980s and early 1990s.

In the past, piecemeal system enhancements were performed to meet new requirements. These piecemeal retrofits have resulted in point designs that only support a particular problem and platform. As a result,

other platforms could not readily leverage these developments. Many of these upgrades were not applicable to subsequent upgrades of the same subsystem, and as time passed, upgrades were layered upon each other compounding the maintenance problem. Tight coupling of the legacy systems forced the major parts of the avionics system to be recertified, which became a major cost driver for the upgrade. Furthermore, these upgrades must be performed and scheduled into the existing maintenance schedule or the existing block upgrade cycle.

upgrades are currently funded. Some issues are structural in the present procurement and management approaches. Decisions are made on a program by program basis, and we see no trend to decrease the authority of the system program directors. Any changes to aging aircraft avionics will have to make sense to the weapons system program director, while providing capabilities and supportability acceptable to the user command. Introduction of a new supportability concept, such as one- or two-level maintenance, will have to prove itself in the context of the existing supportability plan for the weapon system,

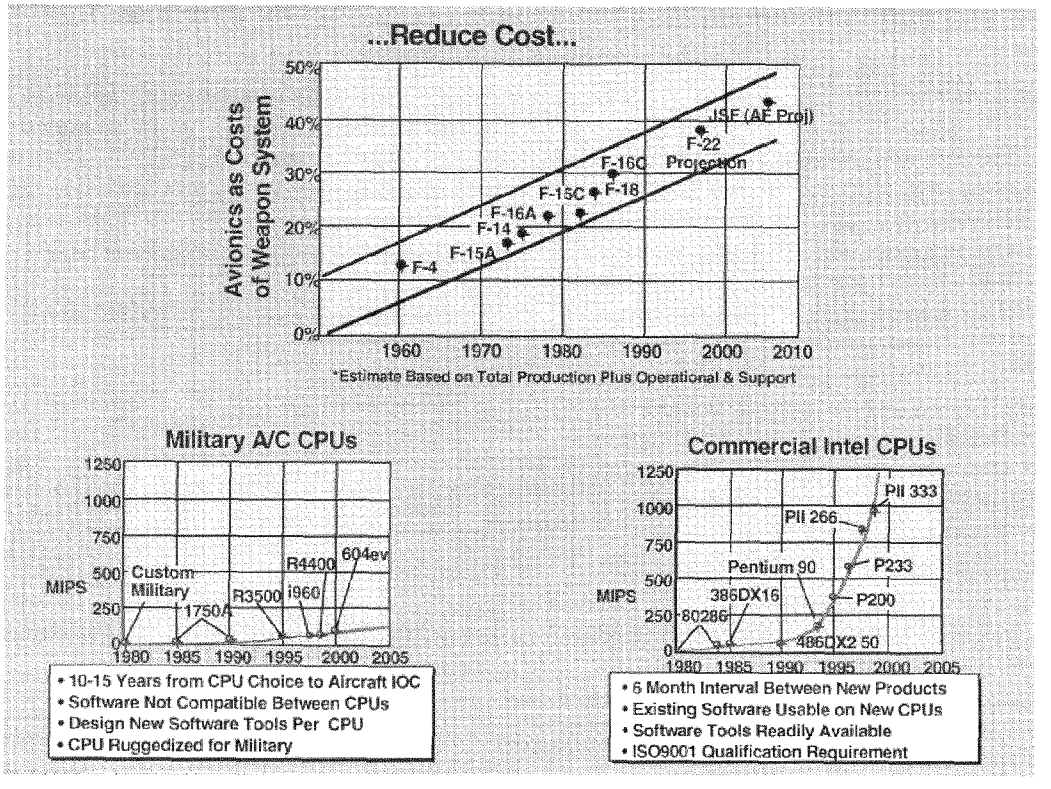


**Figure 2 Commercial and Military Processing Technology Comparison**

Commercial digital technologies have increased in performance several orders of magnitude over the past decade. Advanced data and signal processing capabilities present opportunities for extending the life expectancy and meeting new mission requirements of our existing military aircraft by inserting new capabilities in weapon system platforms.

Beyond commercial technology insertion and basic logistics problems, there are issues of administration, funding, and organization of how

possibly with a 3- to 5-year pay-back.

### Reasons to upgrade

**New and enhanced mission requirements.** Legacy avionics designs are generally based on technology that is at least 15 years old and at least 2-3 orders of magnitude slower than commercial equipment available today. Thus, legacy designs do not have sufficient capacity to meet requirements demanded by the new and enhanced missions, even if significant spare and growth room is built-in.

**Increased reliability and better fault isolation.** Upgrades using modern technology allow for increased reliability because fewer parts and fewer interfaces are required to provide the same functionality, thus providing Life Cycle Cost (LCC) savings potential. This can also lead to better fault isolation because fewer can not duplicate (CND) anomalies are produced.

**Component obsolescence.** The military qualified components used on legacy systems are becoming obsolete at an increasing rate. This provides an opportunity to upgrade the system using COTS parts and the potential for substantial LCC savings.

**Avionics Software**

Modern avionics systems are expensive to upgrade because the software is designed and built to tightly integrate and operate on custom hardware. This situation was driven by the need to squeeze every last cycle out of hardware to implement that next feature. Simply stated, current avionics software is not portable. However, software upgrade and maintenance costs cannot be studied or solved without the defining context of a specific system architecture. Given this situation, major software cost drivers for the upgrade of legacy systems include the following:

1. Recovery and understanding the original system requirements and design constraints. Lack of understanding of these requirements causes rebuilds and sometimes program restarts due to erroneous assumptions and poor design choices based upon incomplete or inaccurate information.
2. Interfacing with the legacy design philosophy of the avionics system and sub-systems. This applies for both hardware and software (language) issues.
3. Interfacing to legacy system operating system environment to meet both scheduling and communication interfaces. Often times this is not a clean interface due to the cyclic nature of most deployed systems and the hardwiring of addressing on the communications bus (i.e. 1553). Traditional approaches to solve these problems (e.g., sharing memory, bus snooping, etc.) are error prone because the new system cannot determine the absolute state of the legacy system.
4. Re-certification and Re-validation of the system and/or sub-system as they are incrementally inserted. The cost of validating the software and hardware for safe and correct operation each time functions change will dominate the cost of any upgrade involving functional modification.
5. Fitting major software/hardware builds and insertion into the normal maintenance cycle. The time to develop and insert a new avionics suite (or a major sub-system) exceeds the standard maintenance cycle.

Upgrading and re-hosting software from a legacy avionics computer to an upgraded one is traditionally a very expensive effort. The software must behave substantially the same on the new processor as on the old one, so interface requirements must be captured and tested. Much legacy code is closely dependent on the architecture and operating system of the legacy computer and is often written in an obsolete computer language. These problems conspire to make direct re-hosting of the code nearly impossible. Several approaches, including reengineering of the code or encapsulating portions of legacy code with modern wrappers, show promise by retaining some of the investment made in the original code development. Other approaches, such as translation and emulation retain even more of that investment at the expense of future maintainability.

Standards apply at all levels of system/software. To aid in the classification of standards, the Society of Automotive Engineers has a reference model called the "Generic Open Architecture model" (GOA). This reference model, shows a detailed breakout of key interfaces for systems. Each of the GOA interface areas are opportunities for reducing the level of interface incompatibility within future systems, improving upgrade opportunities, and providing the basis for procurement guides. For example, IEEE POSIX defines interface standards at the GOA level for operating system and operating system services, and has many commercially available implementations. POSIX allows any application software to be portable to another system that uses a POSIX solution for the level of interface.

Widely commercially used standards (e.g. CORBA or POSIX) provide access to a wider base of professionals that have used the standard, and the implementations of that standard have more operational hours—i.e. fewer defects. This commercial appeal also provides better and greater numbers of available development environments. All these factors lead to lower cost for systems that can take advantage of commercial software interface standards.

Software development cost has been the single major cost driver in most avionics improvement programs. An effective incremental upgrade must utilize COTS technologies to shorten the software development cycle and increase productivity. For MIL-STD-1750 Processor-based software development, few development tools are available, especially for legacy programming languages. Furthermore, it is not uncommon for legacy codes, based on older languages such as FORTRAN and JOVIAL, to become difficult or impractical to maintain as familiarity with the target hardware and highly optimized control and application programs and their development tools diminishes when the engineers who designed them move on. For these reasons, software engineers have begun to migrate away from proprietary, application-specific architectures towards well-defined COTS open systems standards and technologies whenever possible. (See Figure 3) This involves using system environments like DOS, UNIX, VTRX® (MicroTech), VxWorks® (WindRiver); and interfacing to software Application Program Interfaces (API) like Windows® (MicroSoft) or TCP/IP communication protocols.

## Group A modification

Group A modifications involve permanent modifications to flight equipment on the aircraft. Avionics upgrades usually require major Group A modifications at significant cost. Studies conducted by the Modular Avionics System Architecture (MASA) Program on the F-16 fleet indicate that at least three "black box" systems must be integrated into one before modular upgrades can be affordably integrated into a single black box replacement. During this study effort, conducted in 1990 for the F-16, it was concluded that the cost of additional Group A wiring changes could be justified with out-year life cycle cost savings. But as effective service life decreases, the life cycle cost savings are amortized across fewer years. In general, the cross-over point for high rates of aircraft modernization is approximately 10 years of remaining service life. For low rate or low number modernization efforts, Group A development cost is assumed to be the dominate cost inhibitor. In various studies conducted, over twelve change proposals incorporating Group B equipment were altered or

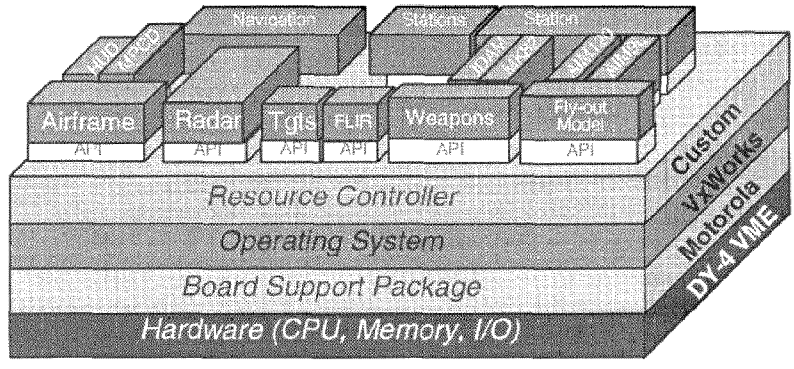


**Figure 3 Open Software Architecture**

structured, well defined languages like C and C++; employing object-oriented programming methods; working within familiar; broadly supported, hardware independent operating

reduced in scope to accommodate limitations of the Group A changes. One significant program was canceled due to estimations for F-16 Group A cost impacts. The results of this analysis

provided an important assumption for aircraft modernization. If future upgrades are small and incrementally funded, the typical upgrade may be projected as a black box one-for-one replacement, referred to herein as in-place upgrade. As Group B black boxes or LRUs are upgraded, the physical wiring, cooling, power, and mechanical interfaces will largely be left unchanged for the remaining service life.

As part of avionics upgrades, modifications to existing aircraft electrical and mechanical configuration items may be required in order to interface with the new elements. These include power, cooling, wiring harnesses, mounting fixtures, cables, connectors, etc. The modifications can be extensive and time consuming when redesigning of existing Line Replaceable Units (LRU), replacing and adding new wiring harnesses, and on aircraft system integration and testing are involved.

A systematic approach that allows insertion of improvements utilizing wiring, installation, and other existing aircraft resources will drastically reduce Group A modification costs. The practice of using field installable modification kits will further reduce time-to-field and unscheduled aircraft down-time.

In addition to electrical and mechanical changes, a major consideration to upgrading legacy avionics is their network architectures. MIL-STD-1553B Multiplexed Bus structure has been the standard for avionics multiplexed communication implementations. While the demand for faster computational capability and data communication of high volume, intermixed data types continues to increase, bridging the MIL-STD-1553B time division multiplex bus-based avionics architecture ( 1 Mbits/sec.) into one that utilizes several orders of magnitude higher network throughput, such as Serial Express, Asynchronous Transfer Mode (ATM), or Gigabit Ethernet, has become necessary to avionics modernization. By expanding the use of existing MIL-STD-1553B cabling in conjunction with a scalable protocol implementation, Group A modification cost can be minimized

Changes to the cooling infrastructure are expensive and usually require changes to the aircraft structure. Thus cooling air found in most legacy aircraft is the heat removal medium. Edge conduction modules have a higher thermal dissipation capability than convection cooled modules, plus they have better vibration and shock performance due to their central heat sink. It may be possible to use liquid edge conduction cooling with heat exchangers to the cooling air in cases where size restrictions and the resultant thermal density of the modules require greater thermal dissipation capability than cooling air provides. In such cases, the liquid cooling infrastructure (circulation and heat exchangers) may have to be self-contained in the avionics upgrade. However, a prototype avionics liquid cooling system for currently fielded aircraft and for the retrofit of state-of-the-art avionics has been demonstrated. The electrically driven vapor-cycle heat pump was integrated into the F-16's current cooling system and increased the cooling capacity by 5KW thus enabling the aircraft to be incrementally updated well into the next millennium with advanced, reliable avionics at low cost.

**Avionics Maintenance**

Typical Operations and Support (O&S) costs run approximately 70% of the total Life Cycle Cost (LCC). Cost distribution is spread over Support Equipment, Depot Maintenance Equipment, Personnel, Initial Training, Initial Technical Data and Initial Spares. To reduce O&S costs, avionics systems must be highly reliable and easy to operate. Timely repair or replacements will minimize Mean Time To Repair (MTTR) and increase Mean Flight Hours Between Unscheduled Maintenance (MFHBUM). Legacy aircraft avionics upgrades must introduce innovations such that system and subsystems level diagnostics can be performed to provide accurate, thorough problem identification and isolation. In addition, periodic preventative maintenance can be automated and prognostic data made available for trend analysis. Hence, non-repeatable anomalies can be eliminated.

"Can Not Duplicate" (CND) faults and "Retest OK" (RTOK) problems account for a large percentage of the maintenance events on legacy aircraft. Better diagnostics will help reduce these problems, but some of the solution must come from the design of the system. Reduction in the number and complexity of interfaces will increase reliability and reduce CNDs. Though CNDs should occur less frequently in a reliable COTS-based system, when they occur, a method

must be provided to save the system state in order to duplicate the situation and attempt to diagnose the cause of the CND in a laboratory.

Mainstream commercial processors and systems do not normally have much diagnostic capability other than at system start time. Some systems are capable of isolating memory errors to a specific failed memory module and some operating systems can probe devices to determine if they are operating normally, but other than that, very little isolation is available. More expensive computers designed for high availability, such as servers and supercomputers, have some built in fault detection and isolation along with redundant hardware to help tolerate the faults. Finally, error correcting/detecting memory controllers can be used to help correct for and diagnose failed memory components. These techniques and others need to be investigated to determine how commercial technology-based avionics upgrades can diagnose and recover from failures and aid maintainers in determining where the failure occurred

Distributed avionics upgrades require system management software to work with the health monitoring software on each processor to maintain a consistent and correct view of the health status of the system. When failures occur, the system manager must activate the programs impacted by the failures on other processing resources. In addition, enough system state must be available to these newly–activated programs so that they can begin operation rapidly and not cause any mission–critical functions to fail for longer than a specified time. An overall system health maintenance and reconfiguration approach must be integral to the upgrade architecture and its associated system software.

Critical to legacy aircraft process evolution is the support strategy and maintenance improvements introduced to legacy aircraft weapon systems. The definition of this support strategy is key to establishing lower operational costs when service life decreases as a function of time remaining in service life. In addition, interfacing the weapon system to the global network is a major goal for future product support systems in order to establish a complete network resource to determine combat status of individual weapon systems for local theater commanders during weapon system deployment. The technology provides users with automated pilot debrief, advanced diagnostics and electronic technical manual data presentation capabilities. The new technology is being used for current legacy aircraft as well as future programs.

The Integrated Maintenance Information Systems (IMIS) technology is a multi-level secure, integrated, distributed task and decision support system that automates numerous processes to improve pilot debrief and maintenance performance functions. IMIS reduces management, supervisory and technical overhead by providing:

1) Real-time access and interface with customer Logistics Data Systems as well as other Department of Defense external systems,

2) Aircraft advanced diagnostics capability, and

3) Display of Interactive Electronic Technical Manuals (IETMs).

The system reduces the hours needed to service, troubleshoot, and repair all aircraft systems and assists in the achievement of the maintenance mission goals of high sortie rates, to minimize aircraft down-time, and to provide maintenance with minimum support resources. Obtaining accurate data of aircraft availability and status is critical to mission planning and repair operations. Achieving timely and accurate data from field operations is an important aspect to understanding when and if weapon systems require modifications to be effective in their missions. As commercial technology is inserted into legacy aircraft systems, it becomes crucial to monitor the field operations of these equipments, as critical built-in-test and self-test hardware and software is generally not built into commercial grade components and systems. Hence the logistic system must be modified to accommodate and control the infusion of technology into the fleet of aircraft and provide a means for technology refresh, as shown in Figure 4.

Aircraft data is received through a data transfer cartridge (DTC) or via an aircraft maintainer vehicle interface (MVI). Although capable of operating as a stand-alone system, the IMIS interface can communicate logistics data through a network connection to external systems. IMIS consists of a networked computer system that

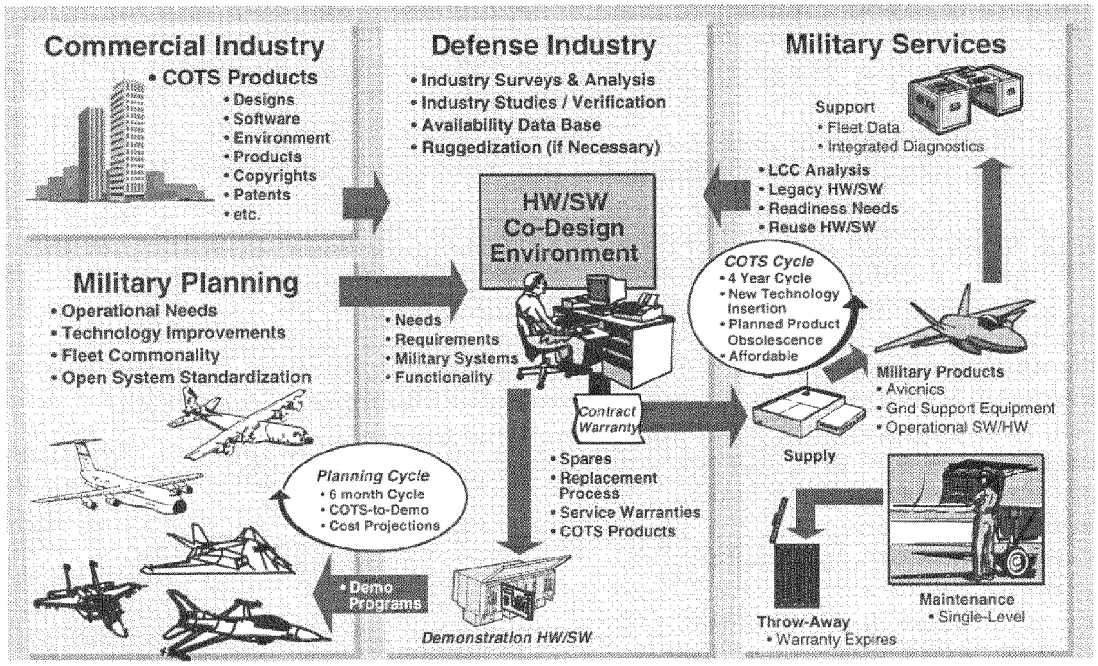


**Figure 4 Logistic Support is a Vital Aspect of Technology Refresh**

communicates with Maintenance Information Workstations (MIW) or Portable Maintenance Aids (PMA). The system components can be transported, allowing use during deployment. Current IMIS development efforts add IMIS capability to provide the system user with real-time access and interface with customer Logistics Data Systems as well as other DoD external systems.

Anticipated benefits of the IMIS system include:

- 50% reduction in pilot debrief time
- 30% improvement in troubleshooting accuracy
- 30% reduction in Re-Test OK (RTOK) rates
- 40% reduction in the time to repair a malfunction or perform maintenance actions resulting in:
- Improved weapon system availability and readiness
- Reduced aircraft down-time
- Improved aircraft sortie rates
- Reduced weapon system life cycle cost
- Improved maintenance data collection

Currently, IMIS is in F-16 field service evaluation and supporting the F-22 Raptor aircraft. Further evaluation is required to potentially add a commercial interface standard such as Ethernet to allow direct access to aircraft weapon systems, either wired, spread spectrum RF, or high speed IR links are being defined as an open systems approach to field service and support. Another element of the IMIS system is the integration of Interactive Electronic Technical Manuals. The Interactive Electronic Technical Manual system allows the user to locate required information faster and more easily than the current paper technical manuals. IETMs are easier to understand, more specifically matched to the system configuration under diagnosis, and are available in a form that requires much less physical storage space than paper. Interactive troubleshooting procedures have been added using the intelligent features of the IETM display device.

### Application of COTS products to upgrades

The use of commercial technology–based components is becoming more and more essential

for avionics upgrades because of the lack of availability of military-qualified parts. In addition, commercial components are normally significantly less expensive and have higher capability than similar military parts. While commercial components are not designed for direct application to military avionics applications, it is expected that methods can be employed that will allow them to operate reliably and cost effectively within avionics environments. The use of COTS components presents other issues that need to be resolved in order to provide a smooth transition to COTS-based avionics, and recoup the cost savings that would make the transition worthwhile.

Due to the differences in the environments of the various legacy platforms, and the resultant variations in requirements, a procurement strategy must be developed that can maximize the benefits of applying COTS to the various platforms. In addition, aircraft will be upgraded in blocks, but the COTS technology used will most likely be obsolete before the block upgrade is complete, so there needs to be a configuration management scheme and continuous upgrade process in place that allows inexpensive insertion of newer components with low-cost revalidation. Methods for certifying the aircraft fleet with the various versions of the block upgrades must be defined. Integration of the COTS-based avionics with the legacy avionics need to be addressed; examples of integration issues include, but are not limited to, interfaces, EMI, and architecture changes. Other areas, such as support equipment and training, will also require attention in order to minimize the cost impacts of the ever-changing COTS technology; this would include such areas as documentation changes as well.

Due to the fact that all aircraft in a fleet are not upgraded at once, some of them will have different hardware configurations than others. Various methods exist for configuring the avionics hardware, both at installation and at maintenance time. One possible technique involves having the avionics system perform a plug-and-play type operation of determining the hardware components it has and loading the appropriate software from a mass storage device.

Another aspect of configuration control is the logistics aspects of the hardware components. It is possible to configure the aircraft in terms of functionality as opposed to part numbers. Hardware components are made to be Form, Fit, Function and Interface ($F^3I$) identical. The components are then tracked according to their $F^3I$ classification and not their part number. Aircraft can then be made to be identical as far as configuration control, and the logistics can be improved due to a reduction in "part numbers" ($F^3I$ numbers). Of course, each component will have to meet some minimum requirements and testing to achieve its $F^3I$ classification.

Mil-Std-490 has been canceled and replaced with a handbook. Government / Industry Data Exchange Process (GIDEP) interaction with just commercial components needs to be fleshed out along with RADC traceability and controls. Mil Std 965, Parts control program, being canceled has be to dealt with philosophically. Is this just a subcontractor issue? Are we partners?

The current trend of higher clock speeds and shorter rise and fall times for digital circuits, plus the small size and increased sensitivity of analog circuitry, presents an opportunity for Electro-Magnetic Interference (EMI) when COTS components are used in avionics applications.

The increased functionality that can be fit onto a module presents the potential for a high density of circuitry in close proximity. Precautions must be taken to prevent analog and digital circuitry from interfering with each other. Moreover, the newer, higher-speed circuitry may present EMI levels that exceed the levels that legacy avionics were designed for. Thus, precautions must be taken to prevent the avionics upgrade and the legacy avionics from interfering with each other.

Because of the rapid advances in commercial computer technology, COTS–based processors should be the most cost–effective part of an avionics upgrade. It is reasonable, therefore, to examine which traditionally analog avionics functions can be handled inexpensively by these processors. Digital radios are becoming available in the commercial arena, so it makes sense to push digital technology as far as reasonable in avionics upgrades. Digitizing at the aperture could eliminate costly waveguides and high–maintenance analog hardware, replacing it with digital networks and signal processing. This

approach to upgrades may reduce cost, weight, and volume, while enhancing maintainability.

**Quality Assurance** - Quality assurance (QA) objectives of military systems must be maintained when applying commercial product QA standards established by the International Standard Organization (ISO). It has been demonstrated that streamlined COTS processes and procedures can reduce Life Cycle Costs and also meet the needs of military applications when applied appropriately.

**Operational Requirements** - Applicable thermal, random vibration, pressure/altitude, electromagnetic and other military operational requirements must continue to be satisfied when COTS elements are introduced in weapon systems. A number of COTS products are presently qualified for many legacy aircraft's avionics operating environments. The associated COTS suppliers have implemented engineering options for meeting different operational requirements.

A technology "bridge" must be continuously maintained into the design of incremental upgrades, so that parts obsolescence and low cost COTS insertion can become facts of life to legacy avionics systems.

## Obsolescence and Rapid Design Changes

The life cycle of microcircuit technology is getting shorter and shorter. In the 60's the market availability life expectancy was 20-25 years. The market availability life expectancy of microcircuits from the 70's was reduced to 15-20 years. This was further reduced in the 80's to 10-15 years. Today the market availability life expectancy of new microcircuits is 7-10 years and this includes introduction and phase-out. In reality, for some of the high-performance microcircuits like processors and memories, the market availability life expectancy is less than 5 years. This presents a problem for military systems, which are generally designed to operate for a life span of 20 to 30 years.

It is not uncommon for military avionics to be obsolete before it is deployed. Many modern systems, including the F-22 and C-17, have undergone major avionics upgrades before achieving operational status. Between the changes in requirements due to the global and national political climates and the rapid evolution of technologies applicable to avionics, the custom architectures created to solve the original problems become rapidly outdated and very expensive to change.

Some of the major cost factors for obsolescence and design changes are described below:

- The current rate of technology turnover in the digital circuit market is staggering. The mean time to obsolescence for all digital parts is around 24 months, and processors are becoming obsolete in less than 18 months. For military avionics, this situation is compounded by the fact that there are a decreasing number of silicon foundries producing military grade parts, and those foundries are producing fewer military parts. It is simply not cost effective for these companies to tie up valuable production capability for a minority market segment. Military parts do not drive the market for digital circuits, and the military supplier must learn to use commercial digital parts to deliver future avionics systems and avionics system upgrades.

  Digital components are not the only system components that are affected by technology change. Software interface standards, bus standards, protocol standards, network standards, and others all change at different rates. Each of these system components are cost risk factors for new or upgrade avionics systems.
- The non-recurring engineering (NRE) required to capture the existing system interfacing requirements is non-trivial. The system documentation does not contain the wisdom of the original designers/implementors, and many times these people are no longer available. Further, the documents do not reflect the current state of the system -- or are missing the fine details to make the system really work. Accurate specifications of the system interfacing and function are required to upgrade avionics systems.
- Beyond the problems of understanding the system interfaces and function, the upgrade avionics system must pass several re-certification levels. Flight qualification, system acceptance, and a number of other tests are required before the upgraded system can be deployed. The cost of re-certification

of avionics systems *can be a major cost driver*.

- One of the major operations and support cost is the logistics to track and store spare parts for aircraft systems. If lifetime buys are considered, several cost factors must be contemplated. First, the sunk cost of the lifetime buy. Second, the additional logistics cost for tracking and storing more parts. Third, the cost risk of those parts becoming obsolete before the parts are used. Finally, the cost of monitoring the obsolescence status of parts within a design. All these cost factors must be considered for the lifetime buy option.

Parts obsolescence is also an issue for military components but not nearly as severe as it is in the highly-competitive COTS environment (see Figure 5). Provisions for the management of obsolescence need to be in place from the beginning of the design process. Obsolescence considerations must be part of any trade-off studies performed in order to select candidate COTS technologies for use in a military system with an extended operational life. One way to manage obsolescence involves drastic changes in the way the military acquires systems. It entails having a number of short development and procurement cycles throughout the life of the system, where upgrades are incorporated into the system. These short development cycles would include the required testing to recertify the integrity of the system. If done right, this approach can eliminate the need for many of the logistic support requirements. If the equipment is highly reliable and low cost, only a small number of spare parts will be required to sustain the system in operation. Upgrades could be available before any failures occur, eliminating the requirements for a complex logistics support structure.

A planned obsolescence approach is required for systems using technologies with a high rate of change. One approach to address this technology change is to develop an overall system architecture that uses well defined (and widely used interfaces) for those items that are subject to rapid obsolescence. Widely used interfaces will tend to have support strategies to get to the next standard (e.g., interface chips that bridge the old interface to the new one). Less popular (or even custom) solutions can be used for system architecture components that do not change rapidly (i.e., antennas or radio frequency amplifiers).

From this baseline upgrade open

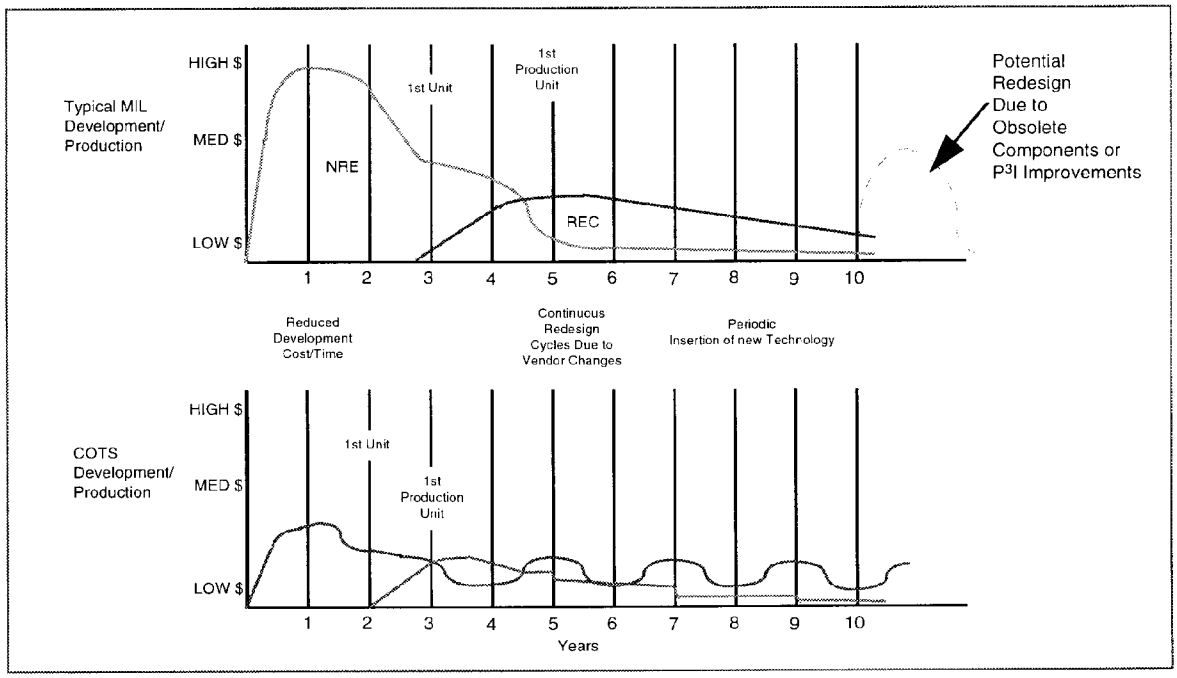


**Figure 5 Contrasting Program Costs**

architecture, portions of the architecture can be inserted incrementally until the system achieves a fully upgraded state. Then as components of that architecture become obsolete, they can be easily replaced with newer generation parts. Part of this approach is the establishment of an obsolescence-management contractor-based sub-IPT early in the program. The IPT would be in charge of:

- Performing detailed obsolescence surveys of potential suppliers
- Maintaining current survey results on file
- Identifying single point-of-contact for obsolescence notification in each of the sub-contractors involved in the program
- Monitoring and maintaining life-cycle ratings for all the active technologies being used in the program
- Rating of technologies longevity by families
- Performing program baseline reviews
- Establishing and maintaining a master parts file repository
- Recording and maintaining a lessons-learned file.

A design capture process using "model-in-the-loop" techniques also helps solve problems with obsolescence of commercial technology-based upgrades. The design capture process results in a detailed executable specification that can be verified using system acceptance tests and other real-world inputs. This executable specification can then be implemented in various ways, including a VHDL-derived replacement part, software emulation, or a modern-technology software simulation. When the first implementation becomes obsolete, due to unavailable parts or for other reasons, a new instantiation of the system can be derived from the executable specification at a substantially reduced cost. This new replacement may or may not use the same implementation choice as the first upgrade, but since the executable specification already exists, little or no time needs to be spent deriving requirements or defining test procedures.

By using executable specifications (e.g., VHDL) to describe digital components, replacement parts that meet the functional specifications can be achieved. Commercial industry routinely uses VHDL to fabricate or program gate arrays and other programmable logic families (e.g., FPGAs, PALs, GALs, etc.) via commercially available synthesis tools. While not perfect, this process can be used to describe large levels of functionality (e.g., processor and I/O boards). Other interfaces (e.g., physical, electrical, ...) can be achieved through the use of custom packages or adapters. This is approach is possible because of the rapid size and form-factor reductions being seen in the programmable logic arena.

**Open System Implementation**

The primary system implications associated with the use of COTS/Best Commercial Practices occur at the avionics architecture level. A major concern is that, taken to the extreme, reduced contractor guidance could result in a "hodgepodge" of custom boxes, modules, display, etc. which will create an integration and maintenance nightmare, destroy competitive procurements (competitors cannot determine how to build compatible hardware and software) and make common, interoperable avionics impossible. Obviously, measures must be taken to avoid this situation.

One measure that has the potential of reducing some of these problems is the use of an Open System Architecture (OSA) for future and current systems. Definitive guidelines of how OSAs will be employed are currently under review by a DoD task force. The OSA approach is aimed at ensuring maximum competition and common avionics, through a readily available set of system specifications that provide adequate information to build interface-compatible hardware and software.

The key is to define an OSA that will permit an incremental upgrade strategy utilizing modular, scaleable components which can be inserted into the diverse set of fielded legacy architectures. This architecture will provide a framework that can be installed in affordable increments into legacy aircraft while retaining coherent system functionality. The ability to incrementally upgrade a system is important, not only due to budget realities, but also because it is typically impractical to complete a major system insertion/replacement within a single normal

maintenance cycle. Aircraft downtime for kit insertion, functional validation and training must be taken into consideration for reducing time-to-field in both engineering and manufacturing development and production phases of an upgrade.

The incremental OSA approach gradually migrates the legacy system to a new coherent, easier-to-upgrade architecture that avoids the current patching problem. These incremental upgrades can be accomplished in less time and at lower cost than would otherwise be imposed by traditional upgrade methods. Closely related to the installation problems (Group A) described earlier are functional interface issues. If incremental and continuous upgrades are to be successful, well defined functional interfaces must be established between the portion that is being upgraded and the portion that is not (see Figure 6). The purpose of these interfaces is to establish boundaries so that the upgraded portion may not affect the functionality of the portion that is not being modified. If this is not done, a "ripple" effect is likely to occur where changes affect parts of the system that don't need to be changed. Not only does this unnecessarily increase the life-cycle cost, it also leads to the unwanted piecemeal designs described above. While new weapon system developments are emphasizing open integrated architectures, these concepts may be difficult to apply to existing systems on an incremental basis. Open systems, properly executed, promote competition and provide value to the customer at lower cost. Distributed open systems are an alternative that bears study, along with domain-specific architectures for displays and display processing, data and satellite communication links, and mission processing upgrades. Specific aspects of an upgrade architecture, such as software re-hosting, would be applied system wide. The issue is the cost of changes to the existing system, including test and maintenance equipment, procedures, and documentation, versus the benefit of a new integrated architecture.

Open interfaces that satisfy widely-used standards are essential to implement incremental upgrades. One upgrade can then benefit from the investment and knowledge base of the previous one, such that we do not waste money solving the same system problem over and over again.

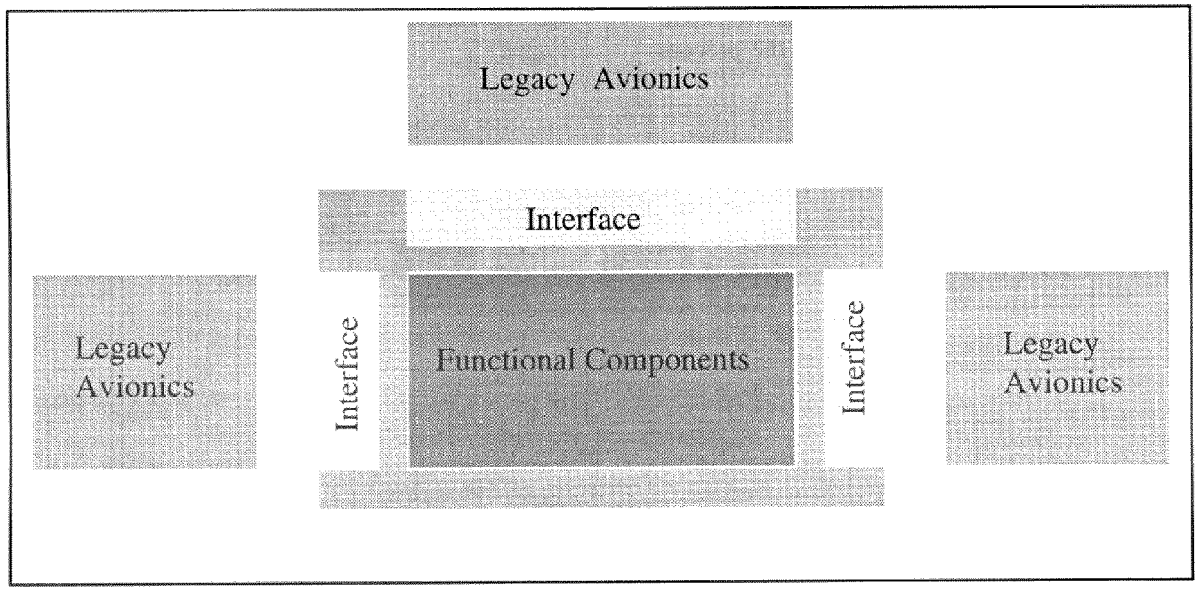


**Figure 6 Upgraded Avionics Integrated Through Well Defined Open Interfaces**

Previous attempts at common module and open interface programs have failed to provide for the future insertion of rapidly evolving digital technology, or have selected interfaces whose usage is limited almost entirely to military systems.

Avionics upgrades generally involve changes to both hardware and software, usually to

accommodate new functional or performance requirements, but occasionally to reduce cost of ownership. We expect that affordable upgrades will become even more of a challenge as the number of software lines of code in our fielded systems increases dramatically during the next decade.

Piecemeal, single-platform upgrades are here to stay as long as the acquisition process is governed by individual program offices and funding horizons are short term. Incremental upgrades are desirable over piecemeal upgrades given the reality of the current budgeting process. Present approaches do not institutionalize the relevant methodologies and architectural concepts, but rather force them to be relearned each time by individual contractor teams. The result is a much longer and more expensive upgrade activity, every time.

## Summary

Industry has embarked on a product-line implementation strategy. The major Weapon System/Aircraft Manufacturers are in the process of defining an open system avionics architecture based on commercial technologies and processes which will be applied across the product lines which they manufacture. Much of this activity is focused on aging aircraft avionics issues to extend the service life of current aircraft coupled with declining military budgets and a dwindling supplier base which challenges the effectiveness of today's front line weapon systems. This approach has been developed by working with numerous government agencies and across the services as well as internal company funding to produce a focused strategy for maintaining the effectiveness of legacy systems while charting a future business strategy similar to large commercially oriented corporations.

Effective use of advanced technologies derived through Science and Technology programs can only be accomplished through a continuous Demonstration and Evaluation Program. This program must be a government/industry partnership aimed at the transition of needed advanced technologies from the research environment to the warfighter. (See Figure 7)

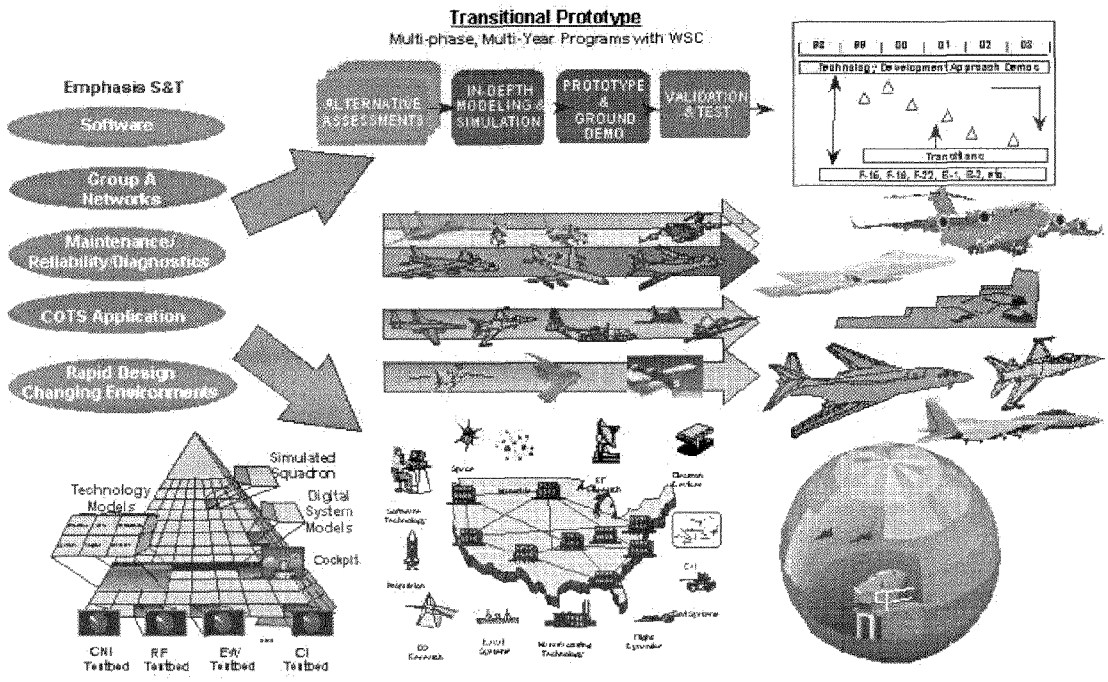


**Figure 7 S&T Transition Methodology**

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